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# PERFORMANCE DECREMENTS IN CONSTANT LOAD WORK FOR SPECIFIC INSPIRATORY AND EXPIRATORY BREATHING RESISTANCES


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This study developed estimates of work performance for specific levels of inspiratory and expiratory resistances. Exercise performance and subjective responses were measured in 5 volunteers during constant load, high intensity work under mask conditions of altered inspiratory resistance (I) and altered inspiratory and expiratory resistance (I+E). Mask performance ratings decreased approximately 17%, 25%, and 42% as inspiratory resistances were increased to 20 mm $H_2O$, 30 mm $H_2O$, and 40 mm $H_2O$ from the control mask level of 9 mm $H_2O$ and expiratory resistance was unaltered. When mask expiratory resistance was increased, performance decrements were 5%, 14%, and 34%, respectively. These observations emphasize the fact that even low levels of breathing resistance will impact performance. However, they also suggest that even slight reductions in the inspiratory and expiratory resistances of current negative pressure masks could improve wearer performance under physical stresses similar to the exercise intensity employed in this study.

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## PREFACE

The work described in this report was authorized under Project No. 10162622A553, CB Defense and General Investigation. This work was started in August 1994 and completed in March 1995.

In conducting the research described in this report, the investigators adhered to Army Regulation 70-25, Research and Development -- Use of Volunteers as Subjects of Research, dated 25 January 1991, as promulgated by the Office of the Surgeon General, Department of the Army. Approval for use of the human volunteers was granted by the U.S. Army Edgewood Research, Development and Engineering Center Human Use Committee, Protocol Log No. 9314S.

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# PERFORMANCE DECREMENTS IN CONSTANT LOAD WORK FOR SPECIFIC INSPIRATORY AND EXPIRATORY BREATHING RESISTANCES

## 1. INTRODUCTION

One objective of the RESPO 21 mask development program is to produce a mask with a 50% reduction in breathing resistance compared to the resistance of current military-type negative pressure respirators (9). However, the amount that wearer work performance can be expected to improve by decreasing breathing resistance is not known. In fact, considerable attention has been paid to this factor in past research investigations but, at most, results have provided only limited insight into defining performance decrements for specific levels of breathing resistances (2,5,6,7,8,10,13,15). In addition, it seems possible that a concentrated effort on developing a mask with a 50% reduction in resistance may not be needed if work performance doesn't differ between a mask with a 40% or even a 30% decrease in resistance compared to a 50% reduction. Therefore, determining reasonable estimates of work performance for specific levels of inspiratory and expiratory resistance would help respirator designers in their efforts by establishing resistance targets that minimally impact performance compared to the unmasked condition.

This study was designed to determine the effects of different inspiratory resistances on performance during constant load work. Our concern was the need to quantify the performance limits of inspiratory resistance breathing during exercise at an intensity that elicits the maximum sensitivity to respiratory factors. This study measured exercise performance and subjective responses at four levels of inspiratory resistance combined with two levels of expiratory resistance.

## 2. METHODS

### 2.1. *Subjects*

Five subjects (3 male and 2 female) volunteered to participate in this study after being briefed on the nature and objective of the study and being advised of the medical risks and safety precautions involved. Subject descriptive characteristics are summarized in Table 1. Volunteers underwent a medical evaluation prior to being accepted for participation to screen for any condition(s) that would prevent safe participation in the study. A written statement of voluntary consent was obtained from each volunteer before testing began.

Table 1. Subjects' characteristics (N = 5).

| Characteristic | Mean ± S.D. | Range |
|---|---|---|
| **Age (yrs)** | 28 ± 5 | 21 - 34 |
| **Weight (Kg)** | 69.7 ± 13.3 | 51.8 - 88.2 |
| $\dot{V}o_{2max}$ **(L·min$^{-1}$)** | 3.48 ± 1.03 | 1.72 - 4.20 |
| **Trait Anxiety Score** | 29 ± 7 | 22 - 41 |

2.2. *Measurements*

Maximal oxygen consumption ($\dot{V}o_{2max}$) and maximal heart rate were determined using the procedures of the Bruce Protocol (4). The test was performed on a motorized treadmill (Quinton Model Q65, Quinton Instrument Co.). Treadmill speeds and grades needed to elicit an exercise intensity of 80-85% of maximum oxygen consumption for the subsequent study trials were determined from the results of this initial test. Heart rates corresponding to this range of functional capacity were also determined and used as an indication that subjects were exercising at the required intensity during subsequent tests. Subjects wore a half-mask designed for exercise and pulmonary function testing (Hans Rudolph, model 7900) instead of a noseclip and mouthpiece for collection of respired gases and ventilatory parameters. Volunteers were clothed in T-shirts, shorts, socks, and sneakers for all exercise trials. Also, subjects were instructed to get adequate rest the night before each trial, to eat a light breakfast or lunch, and to drink plenty of fluids excluding caffeine and alcohol before reporting for their scheduled exercise sessions.

Heart rate was monitored continuously using a bipolar 3-lead ECG (Quinton Q3000 ECG Monitor) during all experimental conditions. Average heart rates were recorded on-line (HP Computer and 3852 data acquisition unit) for every minute of exercise. Both a 12-lead ECG and blood pressure were monitored and recorded during the $\dot{V}o_{2max}$ test. The trait anxiety inventory which evaluates an individual's anxiety proneness (14) was administered prior to each subject's initial exercise trial. The state anxiety inventory which assesses subject anxiety at any particular moment (14) was

completed before and after each of the resistance conditions. Also, subjective measurements of rating of perceived exertion (RPE) (3) for overall effort and breathing comfort (BAC) (1) were recorded every other minute of exercise (Figure 1). Exercise duration while breathing against inspiratory resistance served as the primary measure of subject performance.

2.3. *Experimental procedures*

Following determination of $\dot{V}o_{2max}$, volunteers completed 8 randomly assigned experimental conditions on non-consecutive days. Exercise to exhaustion involved a constant work load that elicited an intensity of 80-85% of $\dot{V}o_{2max}$ under the mask wear conditions of altered inspiratory resistance (I) and altered inspiratory and expiratory resistance (I+E). For the I condition, inspiratory resistance pressures of 9 mm $H_2O$ (the control condition with an unmodified half-mask), 20 mm $H_2O$, 30 mm $H_2O$, and 40 mm $H_2O$ were tested with expiratory resistance held constant at 11 mm $H_2O$ (unmodified mask). For the I+E condition, the same inspiratory resistances were used while expiratory resistance was increased to approximately 20 mm $H_2O$. All pressures were measured at a constant air flow rate of 1.4 $L \cdot sec^{-1}$. Plastic, doughnut-shaped disks, with different sized holes to provide the various resistance levels, were fitted within the inspiratory ports of the half-masks. The subjects were unaware of their particular experimental condition for each test iteration.

Mask inspiratory and expiratory pressures were measured using a variable reluctance pressure transducer (Celesco LCVR, 0-50 cm $H_2O$; Validyne carrier demodulator, model CD 19A). A tap positioned on the front surface of the half-mask approximately mid-way between the wearer's nostrils and mouth was connected to the pressure transducer via tygon tubing. Pressures were recorded on-line in conjunction with heart rate data and were also documented breath-by-breath on a chart recorder (WR 3500 Linearcorder mark 8, Western Graphtec, Inc.).

Exercise was performed on the treadmill in a laboratory environmentally controlled at room temperature (20-24°C). Prior to testing, subjects stood quietly on the treadmill for 3 min while resting data was collected to ensure that the experimental equipment was functioning properly. Subjects then performed a 5 min warm-up of level walking at 1.13 $m \cdot s^{-1}$. Treadmill grade and speed were then increased to elicit an intensity of 80-85% of $\dot{V}o_{2max}$ and subjects proceeded to exercise until they reached a voluntary end-point, referred to as performance time. Following each test, subjects completed an active recovery period of slow treadmill walking until a medical monitor was satisfied that the subject's recovery was within normal limits.

| BREATHING APPARATUS COMFORT SCALE |
|---|

| | |
|---|---|
| 0 | VERY, VERY UNCOMFORTABLE |
| 1 | |
| 2 | VERY UNCOMFORTABLE |
| 3 | |
| 4 | FAIRLY UNCOMFORTABLE |
| 5 | |
| 6 | FAIRLY COMFORTABLE |
| 7 | |
| 8 | VERY COMFORTABLE |
| 9 | |
| 10 | VERY, VERY COMFORTABLE |

| RATING OF PERCEIVED EXERTION |
|---|

| | |
|---|---|
| 0 | NOTHING AT ALL |
| 0.5 | VERY, VERY WEAK |
| 1 | VERY WEAK |
| 2 | WEAK |
| 3 | MODERATE |
| 4 | SOMEWHAT STRONG |
| 5 | STRONG |
| 6 | |
| 7 | VERY STRONG |
| 8 | |
| 9 | |
| 10 | VERY, VERY STRONG<br>MAXIMAL |

FIGURE 1. The Breathing Apparatus Comfort (BAC) and Rating of Perceived Exertion (RPE) scales.

Initial analyses of variance were performed on the data to determine if significant differences existed between the 8 experimental conditions. Duncan's Multiple Range tests were computed to determine significant differences between group means if a significant *F* statistic was initially obtained. Non-parametric data were analyzed using the Kruskall-Wallis analysis of variance and the Mann-Whitney U test for independent samples. For all analyses, significance was accepted at the $p<0.05$ level.

## 3. RESULTS

### 3.1. *Exercise intensities and mask pressures*

The average exercise heart rates and inspiratory and expiratory pressures obtained at the point of exhaustion are summarized in Table 2. No significant differences in heart rate response were observed between conditions, signifying that work load was equal for all exercise trials. Mask inspiratory pressures were significantly greater for the test pressures of 30 mm $H_2O$ and 40 mm $H_2O$ compared to the unmodified mask tests for both conditions of I and I+E. Inspiratory pressures were also greater for the 40 mm $H_2O$ values compared to those recorded during the 20 mm $H_2O$ trials for both I and I+E conditions. In addition, a significant increase in inspiratory pressure was observed between the 20 mm $H_2O$ and 9 mm $H_2O$ test for the I+E condition. Average expiratory pressures did not differ significantly within or between experimental conditions.

### 3.2. *Performance times and anxiety levels*

There were no significant differences in performance times observed within or between I and I+E conditions (Table 3). However, performance time results analyzed with respect to percent performance rating (i.e., computed from (mask results/control results) X 100) (11), showed a significant drop in performance rating for the 40 mm $H_2O$ test pressure compared to the 20 mm $H_2O$ trial for the I+E condition (Figure 2). No significant differences in ratings were observed for the I condition.

Subjects showed relatively stable individual differences in anxiety proneness by exhibiting relatively low trait anxiety scores (Table 1) (14). Subject state anxiety scores increased significantly following exercise with the 40 mm $H_2O$ for both experimental conditions (Table 3). However, the state anxiety scores were similar within and between I and I+E conditions both pre- and post-exercise.

Table 2. Heart rate and mask pressures at breakpoint (N=5).

| TEST CONDITION (mm $H_2O$) | Heart Rate ($b \cdot min^{-1}$) | | Inspiratory Pressure (cm $H_2O$) | | Expiratory Pressure (cm $H_2O$) | |
|---|---|---|---|---|---|---|
| | I | I+E | I | I+E | I | I+E |
| **9** | 178 ± 10 | 178 ± 13 | 2.6 ± 2.1 | 1.5 ± 0.6 | 4.6 ± 3.4 | 6.9 ± 2.6 |
| **20** | 179 ± 6 | 179 ± 9 | 6.8 ± 3.1 | *7.6 ± 2.9* | 4.6 ± 3.1 | 7.8 ± 3.6 |
| **30** | 178 ± 8 | 174 ± 13 | *11.3 ± 5.0* | *10.5 ± 4.6* | 4.3 ± 3.1 | 6.8 ± 3.1 |
| **40** | 173 ± 8 | 171 ± 10 | ***13.6 ± 4.2*** | ***14.5 ± 4.6*** | 4.6 ± 2.7 | 6.8 ± 3.3 |

*Italics* = $p<0.05$ vs. 9 mm $H_2O$
***Bold italics*** = $p<0.05$ vs. both 9 mm $H_2O$ and 20 mm $H_2O$

Table 3. Exercise performance times and anxiety scores (N=5).

| TEST CONDITION (mm $H_2O$) | Exercise Time (min) | | Pre-Exercise Anxiety Score | | Post-Exercise Anxiety Score | |
|---|---|---|---|---|---|---|
| | I | I+E | I | I+E | I | I+E |
| **9** | 18.4 ± 5.1 | 16.9 ± 7.6 | 31 ± 5 | 30 ± 10 | 35 ± 10 | 39 ± 14 |
| **20** | 15.6 ± 6.3 | 16.2 ± 8.2 | 28 ± 8 | 28 ± 10 | 42 ± 11 | 43 ± 9 |
| **30** | 14.1 ± 7.1 | 14.9 ± 8.6 | 28 ± 10 | 28 ± 11 | 41 ± 10 | 43 ± 9 |
| **40** | 11.0 ± 6.0 | 11.8 ± 7.5 | 29 ± 8 | 28 ± 8 | *45 ± 10* | *45 ± 13* |

*Italics* = $p<0.05$ vs. Pre-Exercise scores within I and I+E trials

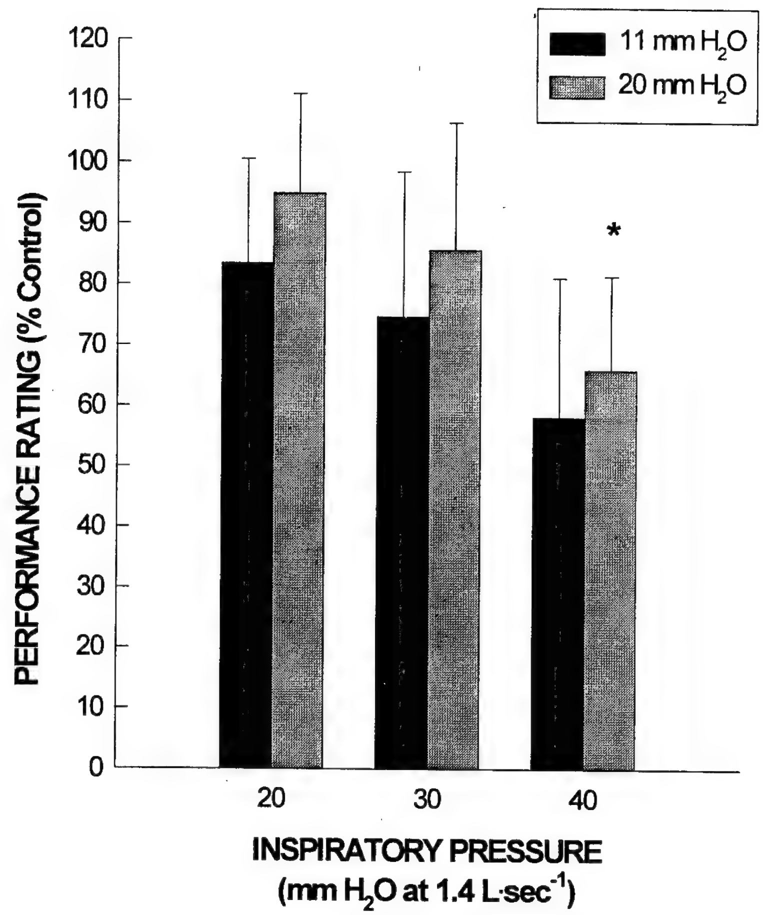


FIGURE 2. Performance ratings for increased inspiratory mask resistances with unmodified (11 mm $H_2O$) and modified (20 mm $H_2O$) expiratory resistances. * = significant difference between the 20 and 40 mm $H_2O$ inspiratory resistance trials.

3.3. *Perceived exertion and breathing comfort*

Subject self-ratings of perceived exertion (RPE) for overall effort remained unchanged with the increased breathing load exerted by the different inspiratory resistances for both the I and I+E conditions (Table 4). Ratings of breathing comfort using the breathing apparatus comfort scale (BAC) indicated significantly greater breathing discomfort for subjects at breakpoint during wear of the 40 mm $H_2O$ inspiratory pressure mask compared to the 9 mm $H_2O$ mask for the I test trials. However, breathing discomfort was significantly greater than the 9 mm $H_2O$ inspiratory resistance mask compared to all other cases for the I+E condition.

Table 4. Breathing comfort (BAC) and perceived exertion (RPE) scores (N=5).

| | **BAC Score** | | **RPE Score** | |
|---|---|---|---|---|
| **TEST CONDITION (mm $H_2O$)** | **I** | **I+E** | **I** | **I+E** |
| **9** | 3 ± 3 | 3 ± 2 | 9 ± 1 | 7 ± 3 |
| **20** | 2 ± 2 | *1 ± 1* | 8 ± 2 | 8 ± 2 |
| **30** | 1 ± 1 | *0 ± 1* | 8 ± 3 | 8 ± 2 |
| **40** | *0 ± 0* | *0 ± 0* | 9 ± 3 | 8 ± 3 |

*Italics* = $p<0.05$ vs. 9 mm $H_2O$

## 4. DISCUSSION

The results of this study indicate that, in general, exercise performance time decreases as inspiratory resistance increases during constant load work of approximately 80-85% $\dot{V}O_{2max}$. This relationship holds true for both low (9 mm $H_2O$) and moderate (20 mm $H_2O$) levels of expiratory resistance. When expressed in terms of performance ratings, relative measures of the performance of a mask wearer compared to the no mask condition, performance decreased approximately 17%, 25%, and 42% as inspiratory resistances were increased to 20 mm $H_2O$, 30 mm $H_2O$, and 40 mm $H_2O$ from the control mask level of 9 mm $H_2O$ and expiratory resistance was unaltered.

When mask expiratory resistance was increased, performance decrements were 5%, 14%, and 34%, respectively. Due to the large variance in performance ratings for the small subject population of this study, no significant differences were found between the two expiratory resistance conditions. However, average performance decrement for the 40 mm $H_2O$ inspiratory and 20 mm $H_2O$ expiratory resistance trials was significantly greater than the 20 mm $H_2O$ inspiratory and 20 mm $H_2O$ expiratory resistance trials.

Restating the observed performance decrements in operational terms, for example, for the 40 mm $H_2O$ inspiratory resistance with unaltered expiratory resistance condition, the 42% decrement implies that a soldier wearing a mask configured with these resistances would only be able to cover 58% of the distance covered without a mask. It follows, then that even for the lowest combinations of inspiratory and expiratory resistances tested in this study, approximately 83% (I) and 95% (I+E) of the distance would be traveled in the masked versus the unmasked condition. These observations emphasize the fact that even low levels of breathing resistance will impact performance. However, some performance decrements during mask wear are unavoidable.

From a design and practical use standpoint, the findings of this study are notable because they quantify the expected performance decrements for specific inspiratory and expiratory pressures. It should be pointed out that the estimates obtained under the controlled conditions of the laboratory may not be directly applicable to field conditions. However, the observed performance times for the exercise intensity used in this study are comparable to those reported in the literature (10,11).

Previous studies have reported that perception of breathing is significantly increased in subjects performing moderate to heavy exercise while wearing a respirator (12,15). Subjective responses to overall physical effort and breathing comfort at breakpoint in the present study further suggest that subjects terminated exercise due to respiratory stress. Ratings of perceived exertion were similar for all conditions. The significantly greater breathing discomfort perceived at breakpoint with the 40 mm $H_2O$ resistance for both expiratory resistance conditions indicates that an increased perception of work of breathing occurred despite equivalent work loads. Interestingly, breathing discomfort differed for each inspiratory resistance condition compared to the control condition when expiratory resistance was increased. However, no differences were observed between the unmodified and modified expiratory resistance conditions, suggesting that the added expiratory resistance had no effect on the perception of breathing discomfort at breakpoint. This was also true for subject anxiety levels.

## 5. CONCLUSIONS

This study developed estimates of work performance for specific levels of inspiratory and expiratory resistances to serve as a guide for respirator designers in their efforts to develop masks that impose lower levels of breathing resistance than those imposed by current military respirators. Results of this study reiterate that performance decrements during respirator wear would be minimized by developing a mask with the lowest resistances possible. However, these results also show even slight reductions in mask inspiratory and expiratory resistance can improve wearer performance under physical stresses similar to the exercise intensity employed in this study.

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